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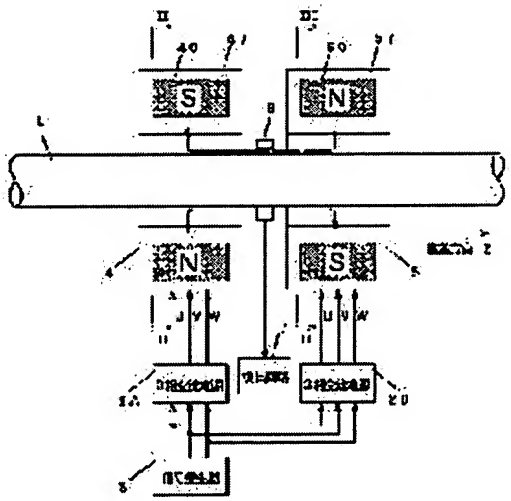
(54) FLAW DETECTOR FOR CONDUCTOR

(57)Abstract:

PURPOSE: To improve an S/N ratio of a flaw detection signal to obtain highly reliable detection results even if a gap between an object to be inspected and a detecting part varies due to vibration during transportation or the like.

CONSTITUTION: A first exciting unit 4 and a second exciting unit 5 which are circular are placed along a transfer direction of an object 1 to be inspected. Magnetic poles formed at opposite positions along the transfer direction of the first exciting unit 4 and the second exciting unit 5 are made to have different poles to generate a magnetic field in the transfer direction at a position of a detecting unit 6. The magnetic field is rotated in a circumferential direction by using three-phase alternating current. The change due to a flaw in eddy current generated on the object 1 is detected as a change in the magnetic field by the detecting unit 6.



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DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Industrial Application] This invention relates to the crack detection equipment of the conductor which can be used for detection of surface cracks, such as a steel bar.
[0002]
[Description of the Prior Art] For example, when detecting a surface crack about an iron steel part, generally inspection is carried out using the vortex flaw detection approach or the magnetic-leakage-flux flaw detection approach. In the vortex flaw detection approach, through is poured in the field generated with the exiting coil, and an inspection object is poured for an eddy current to an inspection object. And since an eddy current changes according to the existence of the surface crack of an inspection object, a detection coil etc. detects the magnetic flux produced by the change. In the magnetic-leakage-flux flaw detection approach, the inspection object which is the magnetic substance is magnetized and the magnetic leakage flux which leaks to the outside by the crack of an inspection object is detected using a sensor.

[0003] While the power of test of eddy current flaw detection is good, it is barred in many cases by the false unnecessary noise signal induced by the magnetic ununiformity of the surface state of **-ed material, for this reason, generally makes a coil differential winding, and is inspecting the surface crack according to the difference of the signal of both coils.
[0004] Signs that **-ed material is inspected with the encircling coil of the self-excitation method most generally used for drawing 15 are shown. As for the coils 4a and 4b which perform excitation and crack detection of an encircling coil 3, the crack signal shown in 21 when the **-ed material 1 passes an annular coil 3 in the arrow-head 20 direction by the direction of a coil being reverse, having become differential winding, and the crack crack 2 being in the **-ed material 1 is acquired respectively. The detection signal of the crack crack 2 by the encircling coil 3 is the same however long the crack crack 2 may be to the longitudinal direction of the **-ed material 1, and since this makes the detection signal the difference of the signal of Coils 4a and 4b, it is because a signal does not occur in two places, the signal a in the front of the crack crack 2, and the signal b in a taele. Moreover, if it is influenced [big] and a crack changes also with the front of the crack crack 2, and the crack configurations of a tail part to **** by the longitudinal direction, although a detection signal will also become high, if the detection signal is loose, it has problems -- a detection signal is low and a power of test declines -- and detection of the crack crack 2 by the encircling coil 3 remained only in the crack in which the crack depth is large.
[0005] In order to cancel the fault of such an encircling coil, the rotational probe coil mold is considered. A probe 5 detects a crack signal for every crack ********, and this aims at improvement in the power of test to a crack crack, as are shown in drawing 16 , and the cross-section hoop direction of the **-ed material 1 is made to rotate the probe 5 which contained the exiting coil and the detection coil as shown in an arrow head 19, a right angle is passed to the crack crack 2 of the **-ed material 1 and it is shown in drawing 16 as 22. However, in order to make a probe 5 cross repeatedly to the crack crack 2, there are many dangers of carrying out the high-speed revolution of the probe 5 around the **-ed material 1, and overlooking intricately [** and a rolling mechanism] difficultly [the flattery to the **-ed material 1 of a probe 5] when the crack crack 2 is short if it is ****, and problems, such as being high.
[0006] As a conventional technique for canceling such a trouble, JP,62-6162,A, JP,62-6163,A, JP,62-123352,A, JP,62-145162,A, JP,62-172258,A, and JP,62-172259,A are well-known, for example.
[0007] In JP,62-6162,A, while installing many detection units which become with an exiting coil and a sensing coil in a circumferencial direction and generating the field of the circumferencial direction of an inspection object, or the direction of a cross section with an exiting coil, inspection of the whole circumferencial direction is enabled by

switching many detection units one by one with a switch.
[0008] Moreover, he is trying to make a circumferencial direction carry out the sequential revolution of the excitation location in JP,62-6163,A and JP,62-123352,A, without exciting an exiting coil using the three-phase alternating current, and using a switch, while installing many detection units which become with an exiting coil and a sensing coil in a circumferencial direction and generating the field of the circumferencial direction of an inspection object, or the direction of a cross section with an exiting coil.
[0009] Moreover, he separates mechanically the detection unit of each other installed in the circumferencial direction, and is trying to maintain a gap with an inspection object uniformly for every detection unit in JP,62-145162,A.
[many]
[0010] In JP,62-172258,A and JP,62-172259,A, while generating the field rotated one by one to the circumferencial direction of an inspection object, many sensors are arranged in this circumferencial direction, and the technique which samples the output of many sensors one by one is indicated synchronizing with the revolution of the generated field.
[0011]
[Problem(s) to be Solved by the Invention] These techniques are inherent in the following common faults, even if an advantage is in each. For example, at JP,62-6162,A, in order to use the exiting coil further shown in drawing 19 by JP,62-145162,A in order to use an exiting coil and a sensing coil as shown in drawing 17 , and in order to use the exiting coil shown in drawing 18 by JP,62-6163,A and JP,62-123352,A, the magnetic flux from an exiting coil is produced in radial [of inspected material]. On the other hand, by the excitation method of the penetration mold shown in conventional drawing 15 , magnetic flux is generated in the direction of straight side (shaft) of inspected material.
[0012] By the way, although S/N (it is the ratio of the flaw signal S and the base noise N, and the ease of detecting of a flaw is expressed) in automatic testing is generally called need 3 or more times By gap fluctuation of a detector and an inspection object, although S/N becomes good so that S/N of this signal of the gap of a detector and an inspection object is small Since a actual inspection process inspects conveying the steel bar which is for example, an inspection object at high speed, it cannot narrow a gap extremely on balance with ******.
[0013] Moreover, since an inspection object vibrates by conveyance, the gap of a detector and inspected material is always changed. Under the present circumstances, since [whose magnetic flux from an exiting coil is inspected material] flux density will change with gap fluctuation remarkably if generated radially, sensibility change of about [that fluctuation of a base noise is large] and a flaw signal takes place extremely, and there is a fault in which S/N gets worse remarkably.
[0014] However, when the shaft orientations of inspected material are made to generate the magnetic flux from an exiting coil as shown in drawing 15 , change of the flux density of inspected material radial [by gap fluctuation] has the advantage which becomes comparatively small. Therefore, this invention is making it generate instead of the above-mentioned probe rotary system, making a hoop direction rotate the magnetic flux of the shaft orientations of inspected material, improves the S/N ratio of the signal acquired to the crack of an inspection object, and makes it a technical problem to raise the dependability of crack detection.
[0015]
[Means for Solving the Problem] In order to solve the above-mentioned technical problem, the crack detection equipment of the conductor of claim 1 The 1st excitation means which is a form surrounding the periphery of the inspection object conveyed by predetermined shaft orientations (4); It is a form surrounding the periphery of said inspection object. The 2nd excitation means installed in a different location from said 1st excitation means (5); Between said 1st excitation means and the 2nd excitation means, The field which magnetic-flux detection means (6 7); installed in the front face of said inspection object and the location which counters and said 1st excitation means, and the 2nd excitation means generate It has excitation control means (2A, 2B); which generates a field so that it may be suitable in the conveyance direction of said inspection object and may rotate to the circumferencial direction of said inspection object in the location of said magnetic-flux detection means.
[0016] Moreover, the crack detection equipment of the conductor of claim 2 contains two or more exiting coils arranged almost annularly in the form surrounding the periphery of the inspection object (1) conveyed by predetermined shaft orientations. The excitation means of the 1st set (4); Two or more exiting coils arranged almost annularly in the form surrounding the periphery of said inspection object are included. The excitation means of the 2nd set installed in a different location from said excitation means of the 1st set to said shaft orientations (5); while rotating to the circumferencial direction of said inspection object, the field which said excitation means of the 1st set and the excitation means of the 2nd set generate To the exiting coil pair which counters said shaft orientations mutually [the excitation means of the 1st set, and the excitation means of the 2nd set] It has magnetic-flux detection means (6 7); installed in the front face of said inspection object between excitation control means (2A, 2B); which forms a mutually

different magnetic pole at the same event and said excitation means of the 1st set, and the excitation means of the 2nd set, and the location which counters.
[0017] moreover, the difference which detects the difference of the signal which two detection means to by_which come to arrange said inspection object in the form to surround annularly, and said magnetic-flux detection means adjoins further mutually two or more detection means counter with a part of circumferencial direction of the each aforementioned inspection object, among two or more of said detection means in it in claim 3 output -- a detection means (71) includes.
[0018] Moreover, in claim 4, said excitation control means includes the polyphase current power source more than a three phase circuit.
[0019] In addition, although the notation shown in the above-mentioned parenthesis shows the sign of the element with which it corresponds in the example mentioned later by reference, each component of this invention is not limited only to the concrete element in an example.
[0020]
[Function] In invention of claim 1, it is arranged in the form where the 1st excitation means (4) and the 2nd excitation means (5) surround the periphery of an inspection object (1), respectively, and the 1st excitation means (4) and the 2nd excitation means (5) are installed in the location mutually shifted to the shaft orientations by which an inspection object is conveyed. Moreover, between said 1st excitation means and the 2nd excitation means, the magnetic-flux detection means (6 7) is installed so that it may counter with the front face of said inspection object. And an excitation control means (2A, 2B) controls a field so that the field which said 1st excitation means and the 2nd excitation means generate is suitable in the conveyance direction of said inspection object and rotates to the circumferencial direction of said inspection object in the location of said magnetic-flux detection means.
[0021] Moreover, in claim 2, the excitation means (4) of the 1st set and the excitation means (5) of the 2nd set contain two or more exiting coils arranged almost annularly in the form which surrounds the periphery of an inspection object (1), respectively, and the excitation means (4) of the 1st set and the excitation means (5) of the 2nd set are installed in the location mutually shifted to the shaft orientations by which an inspection object is conveyed. And an excitation control means (2A, 2B) forms a mutually different magnetic pole at the same event in the exiting coil pair which counters said shaft orientations mutually [the excitation means of the 1st set, and the excitation means of the 2nd set] while rotating the field which the excitation means of the 1st set and the excitation means of the 2nd set generate to the circumferencial direction of said inspection object. Moreover, between the excitation means of the 1st set, and the excitation means of the 2nd set, a magnetic-flux detection means (6 7) is installed so that it may counter with the front face of said inspection object.
[0022] Thus, if constituted, as for the field in the space between the excitation means of the 1st set and the excitation means of the 2nd set which a magnetic-flux detection means is installed, the component (Bz) of said shaft orientations will become dominant. That is, the magnetic path which goes to one magnetic pole of the excitation means of the 2nd set from one magnetic pole of the excitation means of the 1st set (to or the objection) is formed. Since this magnetic path adjoins the front face of an inspection object, an eddy current flows on an inspection object by the magnetic flux which passes along it. Although the direction where an eddy current flows becomes settled with the sense of the magnetic flux generated by each excitation means, when a crack is shown in the front face of an inspection object, an eddy current flows so that a crack may be bypassed. A magnetic-flux detection means (6 7) detects the magnetic flux produced according to the eddy current on an inspection object. Therefore, if an eddy current changes with the existence of the crack on an inspection object, it will be detected by the magnetic-flux detection means and the existence of a crack will be detected. Since it rotates to the circumferencial direction of an inspection object, the field which the excitation means of the 1st set and the excitation means of the 2nd set generate can detect the crack of each location of a circumferencial direction.
[0023] Although this invention detects a crack in the condition of having made parallel exciting an inspection object toward the conveyance direction (Z), conventional crack detection equipment is detecting the crack, where an inspection object is excited in the circumferencial direction or the direction of a cross section. As for the S/N ratio of the signal acquired by the crack, according to the experiment, also in any in the condition that the inspection object is standing it still, and the condition (condition of changing the gap of a magnetic-flux detection means and an inspection object) that the inspection object is vibrating by conveyance, the result with the, far more sufficient equipment of this invention than conventional equipment was obtained. Therefore, reliable crack detection is realized.
[0024] the difference which detects the difference of the signal which two detection means to by_which come to arrange said inspection object in the form to surround annularly, and a magnetic-flux detection means adjoins further mutually two or more detection means counter with a part of circumferencial direction of the each aforementioned

inspection object, among said two or more detection means in it in claim 3 output -- a detection means (71) is included. That is, change of magnetic-flux distribution (magnetic-flux distribution produced according to an eddy current) in the location which adjoins the circumferencial direction of an inspection object mutually is detected as a crack on an inspection object.

[0025] In claim 4, an excitation control means includes the polyphase current power source more than a three phase circuit. That is, by rotating an excitation field using a polyphase current power source, the space higher harmonic produced in an excitation field can be reduced, the unevenness of a field becomes small, and crack detection stabilized more is realized.

[0026]

[Example] The configuration of the crack detection equipment of an example is shown in drawing 1 , the II-II line cross section of drawing 1 is shown in drawing 2 , and the III-III line cross section of drawing 1 is shown in drawing 3 . With reference to drawing 1 , it explains first. The steel bar 1 which is an inspection object is manufactured with a hot rolling line, and it is rolled out continuously, being conveyed at high speed by the shaft orientations (longitudinal direction). In this example, crack detection equipment is arranged so that the path of a steel bar 1 may be surrounded to the appearance side like a finish roll turner. In addition, in the location of crack detection equipment, since the temperature of a steel bar 1 is more than a Curie point, a steel bar 1 is non-magnetic material.

[0027] The body of crack detection equipment consists of three-phase-circuit AC-power-supply 2A, 2B, a signal generator 3, the 1st excitation unit 4, a 2nd excitation unit 5, a detection unit 6, and a detector 7. The 1st excitation unit 4 consists of exiting coils 47 of the annular iron core 40 arranged so that a steel bar 1 may be surrounded, and a large number wound around it. The exiting coil 47 has become actually with 24 coils arranged at equal intervals at the circumferencial direction as shown in drawing 2 . Moreover, since connection of these coils is carried out as a dotted line shows, these are classified into every four-piece guru [6 sets of exiting coil]-PU 41, 42, 43, 44, 45, and 46. That is, as shown in drawing 4 , exiting coil guru-PU 41, 42, 43, 44, 45, and 46 is excited by the power source of +U phase, -V phase, +W phase, -U phase, +V phase, and -W phase, respectively.

[0028] Similarly, the 2nd excitation unit 5 consists of exiting coils 57 of the annular iron core 50 arranged so that a steel bar 1 may be surrounded, and a large number wound around it. The exiting coil 57 has become actually with 24 coils arranged at equal intervals at the circumferencial direction as shown in drawing 3 . Moreover, since connection of these coils is carried out as a dotted line shows, these are classified into every four-piece guru [6 sets of exiting coil]-PU 51, 52, 53, 54, 55, and 56. That is, as shown in drawing 4 , exiting coil guru-PU 51, 52, 53, 54, 55, and 56 is excited by the power source of -U phase, +V phase, -W phase, +U phase, -V phase, and +W phase, respectively.

[0029] As shown in drawing 1 , three-phase-circuit AC-power-supply 2A generates the power supplied to the 1st excitation unit 4, and three-phase-circuit AC-power-supply 2B generates the power supplied to the 2nd excitation unit 5. Three-phase-circuit AC-power-supply 2A and 2B generate the alternating current power of a three phase circuit (U, V, W) synchronizing with the three-phase-circuit AC signal which a signal generator 3 outputs, respectively. Therefore, the phase of the alternating current power of the three phase circuit which three-phase-circuit AC-power-supply 2A outputs, and the alternating current power of the three phase circuit which three-phase-circuit AC-power-supply 2B outputs synchronizes mutually.

[0030] And as shown in drawing 4 , as for the power supplied to exiting coil guru-PU in the location where the 1st excitation unit 4 and the 2nd excitation unit 5 counter mutually, the polarity is reverse mutually to the shaft orientations of a steel bar 1. When the magnetic pole which is got blocked, for example, is generated by energization of exiting coil guru-PU 41 is the south pole, the magnetic pole generated by energization of exiting coil guru-PU 51 turns into N pole. Moreover, when the magnetic pole generated by energization of exiting coil guru-PU 41 is an N pole, the magnetic pole generated by energization of exiting coil guru-PU 51 turns into the south pole. For this reason, the field which goes to the direction where the 1st excitation unit 4 and the 2nd excitation unit 5 counter mutually, i.e., the shaft orientations of a steel bar 1, occurs.

[0031] The detection unit 6 is annularly constituted so that a steel bar 1 may be surrounded, and it is arranged in the middle location of the 1st excitation unit 4 and the 2nd excitation unit 5. The flux density distribution around the steel bar 1 in the location of the detection unit 6 formed of excitation of the 1st excitation unit 4 and the 2nd excitation unit 5 was calculated and searched for by computer simulation. The result is shown in drawing 8 . In addition, the imaginary part shown in the real part shown in the drawing 8 upside and the bottom shows the condition that the phase of a power-source wave shifted 90 degrees mutually.

[0032] Furthermore, the result of having decomposed the flux density distribution around the steel bar 1 in the location of the detection unit 6 into the component of each shaft orientations is shown in drawing 9 as flux density in circumferencial direction each location. In drawing 9 , Bz, Bt, and Br show the flux density of Z shaft orientations

(longitudinal direction of a steel bar), the direction of a path of a steel bar, and a circumferencial direction, respectively. That is, about the flux density in the location of the detection unit 6, that the component of Z shaft orientations is dominant can understand from drawing 9 .

[0033] Moreover, time amount transition of flux density distribution of Z shaft orientations in the location of the detection unit 6 is shown in drawing 10 . Here, T is one period (1 / 60 seconds) of the signal which a signal generator 3 outputs. If drawing 10 is referred to, he can understand that distribution of flux density moves to a circumferencial direction with time amount. That is, the field formed in the location of the detection unit 6 turns into rotating magnetic field which rotate the perimeter of a steel bar 1 to a circumferencial direction. As shown in drawing 1 at a certain event, the one south pole and one N pole are formed on the 1st excitation unit 4. One N pole and the one south pole are formed on the 2nd excitation unit 5, and big flux density is obtained in the location of the detection unit 6 between the south pole of the 1st excitation unit, and N pole of the 2nd excitation unit, and between N pole of the 1st excitation unit, and the south pole of the 2nd excitation unit.

[0034] Next, it explains with reference to drawing 11 . As mentioned above, excitation of the 1st excitation unit 4 and the 2nd excitation unit 5 produces the field H of Z shaft orientations near the front face of a steel bar 1. By this field H, an eddy current i flows toward a circumferencial direction in the front face of the steel bar 1 which is a conductor. However, since it flows so that an eddy current may bypass crack 1a, when crack 1a exists in the front face of a steel bar 1, near the crack 1a, it is component i" of Z shaft orientations to an eddy current. It is generated. This eddy current i" The field H2 of a circumferencial direction arises. When crack 1a does not exist, the field H2 of a circumferencial direction is hardly produced. Therefore, if the field H2 of a circumferencial direction is supervised, the existence of crack 1a is detectable.

[0035] The detection unit 6 is installed in order to detect the field H2 of a circumferencial direction. The configuration of the detection unit 6 is shown in drawing 12 . Drawing 12 develops a circumferencial direction to a lengthwise direction, and shows the appearance of the detection unit 6. Moreover, the V-V line cross section of drawing 12 is shown in drawing 5 . Reference of drawing 12 constitutes the detection unit 6 from detecting elements 6A and 6B of two trains put in order where Z shaft orientations are approached mutually. Detecting-element 6A equips the circumferencial direction with 30 coil plate 6Aa(s), 6Ab, 6Ac, 6Ad, and .... which were put in order at equal intervals. The same is said of detecting-element 6B. Every two by which these coil plates adjoin a circumferencial direction mutually are a pair, respectively.

[0036] One pair of configurations of coil plate 6Aa and 6Ab are shown in drawing 6 . Coil plate 6Aa and 6Ab(s) have the spiral coil 62 respectively formed with the conductor of the shape of a foil printed on the resin substrate 61. Lead-wire 63a or 63b is connected to the end of the outside of a coil 62. The end inside the coil 62 of coil plate 6Aa and the end inside the coil 62 of coil plate 6Ab are mutually connected by lead wire 64. The same is said of other coil plate 6Ac(s), 6Ad, 6Ae, 6Af, and ...

[0037] The magnetic flux produced by the field H2 interlinks with a coil 62, and an electrical potential difference carries out induction to a coil 62. When crack 1a does not exist in the steel bar front face of a pair of coil plate (for example, 6Aa(s), 6Ab) and the location which counters, the electrical potential difference which carries out induction to two coils 62 becomes almost equal, but when crack 1a exists in the steel bar front face of one side of a pair of coil plate, and the location which counters and a crack does not exist in the location of another side, a difference arises on the electrical potential difference which carries out induction to two coils 62. Therefore, since the potential difference which appears between lead-wire 63a and 63b becomes large when there is crack 1a, crack 1a is detectable by supervising the potential difference.

[0038] The configuration of the part connected to coil plate 6Aa of a couple and 6Ab among detectors 7 is shown in drawing 7 . Moreover, the example of a signal of each part of the circuit shown in drawing 7 is shown in drawing 13 . If drawing 7 is referred to, the differential amplifier 71 will amplify the difference of the electrical potential difference SA in which the coil of coil plate 6Aa carries out induction, and the electrical potential difference SB in which the coil of coil plate 6Ab carries out induction, and will output it as a signal SC. Signal SC is inputted into Schmidt Trigger 74 through an inversed amplifier 72 while it is inputted into Schmidt Trigger 73. If the amplitude of Signal SC becomes more than predetermined, Schmidt Trigger 73 and/or the output of 74 will be set to high-level H. OR gate 75 generates the crack detecting signal SD based on the signal which Schmidt Trigger 73 and 74 outputs. The detector of the configuration same also about the pair of other coil plates (6Ac, 6Ad, 6Ae, 6Af, ...) as what is shown in drawing 7 , respectively is connected.

[0039] As mentioned above, the fields H produced by excitation of the 1st excitation unit 4 and the 2nd excitation unit 5 are rotating magnetic field, and a part with large flux density rotates them at a fixed rate to the circumferencial direction of a steel bar 1. And an eddy current flows into a part with the large flux density on a steel bar 1, and the

existence of a crack is detected using this eddy current. Therefore, the location set as the object of crack detection is also moved to a circumferencial direction with the revolution of Field H. Crack 1a on a steel bar 1 is detected by a pair of coil plate (for example, 6Aa(s), 6Ab) which exists in it and the location which counters.

[0040] In this example, about the detecting elements 6A and 6B of two trains arranged in Z shaft orientations, it has connected so that the pair of a coil plate may become alternate. Namely, although coil plate 6Aa and 6Ab, 6Ac and 6Ad, 6Ae and 6Af, and ... are making the pair about detecting-element 6A of eye one train, respectively as shown in drawing 12 About detecting-element 6B of eye two trains, coil plate 6Bb and 6Bc, 6Bd and 6Be, 6Bf and 6Bg, and ... are making the pair, respectively, and coil **** of detecting-element 6B of eye two trains is located between coil **** and coil **** of detecting-element 6A of eye one train which adjoin mutually.

[0041] For example, although a crack is detected by them, it is difficult in the location coil plate 6Aa of a circumferencial direction, and near the 6Ab to detect a crack near coil plate 6Ab and the 6Ac by coil **** 6Aa and 6Ab, or coil **** 6Ac and 6Ad. However, near coil plate 6Ab and the 6Ac, a crack is detectable with coil **** 6Bb and 6Bc of detecting-element 6B of eye two trains. Therefore, crack detection can be performed in every location of a circumferencial direction, and the field (neutral zone) in which crack detection is impossible is not produced.

[0042] The configuration of three-phase-alternating-current power-source 2A of drawing 1 is shown in drawing 14 . In addition, the configuration of three-phase-alternating-current power-source 2B is also the same as that of drawing 14 . It explains with reference to drawing 14 . It is rectified by the thyristor bridge 22 and smoothness of the alternating current power supplied from three-phase power 21 is carried out by the inductor 25 and the capacitor 26. Therefore, direct current voltage appears between the terminals of a capacitor 26. The electrical potential difference which appears between the terminals of a capacitor 26 changes according to the phase to which the trigger of the thyristor bridge 22 is carried out. The electrical-potential-difference command value Vdc impressed to the phase angle calculation machine 24 is used for adjustment of the direct current voltage which appears between the terminals of a capacitor 26. The phase angle calculation machine 24 computes the trigger phase angle alpha corresponding to the electrical-potential-difference command value Vdc. A gate driver 23 generates the trigger signal impressed to each gate terminal so that the trigger of each thyristor of the thyristor bridge 22 may be carried out by the trigger phase angle alpha which the phase angle calculation machine 24 outputs. That is, a trigger signal is generated when the time amount equivalent to the phase angle alpha has passed, after detecting the zero crossing point of the alternating current wave form which each thyristor switches, respectively and detecting a zero crossing point.

[0043] The transistor bridge 27 switches the direct current voltage which appears between the terminals of a capacitor 26, and generates the three-phase-alternating-current electrical potential differences U, V, and W. The signal which controls switching of the transistor bridge 27 is generated by the comparator 29, and is impressed to the base terminal of each transistor through a gate driver 28. The output of a signal generator 3 and the output of the chopping sea generator 30 are connected to the input terminal of a comparator 29. A signal generator 3 outputs the three-phase-alternating-current electrical potential differences U1, V1, and W1 of the sine wave whose frequency is 60Hz. U1, V1, and V1 and W1 have the phase contrast of 120 degrees, respectively. Moreover, the chopping sea generator 30 outputs the chopping sea signal whose repeat frequency is 3kHz. The comparator 29 builds in six analog comparators and outputs those comparison results as six binary signals as compared with the electrical potential difference of the chopping sea to which the chopping sea generator 30 outputs the electrical potential difference of the forward half wave of the three-phase-alternating-current electrical potential differences U1, V1, and W1, and a negative half wave with the analog comparator which became independent, respectively. These binary signals are impressed to the transistor bridge 27 through a gate driver 28, and the three-phase-alternating-current electrical potential differences U, V, and W appear in the output of the transistor bridge 27.

[0044] It was confirmed by the experiment that the crack detecting signal (SC) in the crack detection equipment of this example has the very big S/N ratio. Moreover, even if it was the case where the amount of fluctuation of the gap of the detection unit 6 and a steel bar 1 was about 1mm, it turned out that about 2.5 S/N ratio is obtained to the crack whose depth is 0.5mm.

[0045] In addition, in the above-mentioned example, although the inspection object was explained as a steel bar, if it is a conductor, the thing of other construction material can also be inspected. Moreover, in an example, although the three-phase-alternating-current power source was used as a power source which energizes the excitation units 4 and 5, the polyphase current power source exceeding a three phase may be used. Since the space higher harmonic of the field produced with the excitation units 4 and 5 is reduced more as a source resultant pulse number increases, crack detection stabilized more is realized.

[0046] Moreover, in the above-mentioned example, although constituted from a coil plate of a large number which arranged the detection unit 6 in the circumferencial direction, even if it uses the field detector of various configurations

better known than before, it is possible to detect a crack.

[0047]

[Effect of the Invention] In this invention, since a crack is detected in the condition of having made parallel exciting an inspection object toward the conveyance direction (Z), the S/N ratio of the signal acquired by the crack is substantially improved compared with the former, and reliable crack detection is realized. Moreover, since an excitation field is rotated to a circumferencial direction, crack detection can be performed in each location of a circumferencial direction, and both the cracks of a circumferencial direction can also detect the crack of a longitudinal direction.

[0048] Moreover, in claim 3, since change of magnetic-flux distribution (magnetic-flux distribution produced according to an eddy current) in the location which adjoins the circumferencial direction of an inspection object mutually is detected as a crack on an inspection object, the existence of a crack can be detected for every small region of a circumferencial direction, respectively, and detectability ability improves. For example, both cracks are detectable to the inspection object which exists in the location where two or more cracks in which the depth differed greatly approached mutually.

[0049] Moreover, in claim 4, by rotating an excitation field using a polyphase current power source, the space higher harmonic produced in an excitation field can be reduced, the unevenness of a field becomes small, and crack detection stabilized more is realized.

[Translation done.]

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CLAIMS

[Claim(s)]
[Claim 1] The 1st excitation means which is a form surrounding the periphery of the inspection object conveyed by predetermined shaft orientations; It is a form surrounding the periphery of said inspection object. The 2nd excitation means installed in a different location from said 1st excitation means; Between said 1st excitation means and the 2nd excitation means, The field which magnetic-flux detection means; installed in the front face of said inspection object and the location which counters and said 1st excitation means, and the 2nd excitation means generate Crack detection equipment of the conductor equipped with excitation control means; which generates a field so that it may be suitable in the conveyance direction of said inspection object and may rotate to the circumferencial direction of said inspection object in the location of said magnetic-flux detection means.
[Claim 2] Two or more exiting coils arranged almost annularly in the form surrounding the periphery of the inspection object conveyed by predetermined shaft orientations are included. The excitation means of the 1st set; Two or more exiting coils arranged almost annularly in the form surrounding the periphery of said inspection object are included. The excitation means of the 2nd set installed in a different location from said excitation means of the 1st set to said shaft orientations; while rotating to the circumferencial direction of said inspection object, the field which said excitation means of the 1st set and the excitation means of the 2nd set generate To the exiting coil pair which counters said shaft orientations mutually [the excitation means of the 1st set, and the excitation means of the 2nd set] Crack detection equipment of a conductor equipped with magnetic-flux detection means; installed in the front face of said inspection object between excitation control means; which forms a mutually different magnetic pole at the same event and said excitation means of the 1st set, and the excitation means of the 2nd set, and the location which counters.
[Claim 3] the difference which detects the difference of the signal with which two detection means come to arrange said inspection object in the form to surround annularly, and adjoin further mutually a part of circumferencial direction of the each aforementioned inspection object and two or more detection means counter, among two or more of said detection means in it output said magnetic-flux detection means -- the crack detection equipment including a detection means of said conductor according to claim 2.
[Claim 4] Said excitation control means is crack detection equipment including the polyphase current power source more than a three phase circuit of said conductor according to claim 2.

[Translation done.]

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DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] It is the block diagram showing the configuration of the crack detection equipment of an example.
[Drawing 2] It is the II-II line sectional view of drawing 1 .
[Drawing 3] It is the III-III line sectional view of drawing 1 .
[Drawing 4] It is the perspective view showing distribution of the excitation phase of the excitation units 4 and 5.
[Drawing 5] It is the V-V line sectional view of drawing 12 showing the detection unit 6.
[Drawing 6] It is the perspective view showing coil plate 6Aa of a couple, and 6Ab.
[Drawing 7] It is the block diagram showing a part of detection unit 6 and detector 7.
[Drawing 8] It is the vector diagram showing the flux density distribution in the location of the detection unit 6.
[Drawing 9] It is the graph which shows circumferencial direction distribution of each shaft-orientations component of the flux density of drawing 8 .
[Drawing 10] It is the graph which shows time amount transition of Bz of drawing 9 .
[Drawing 11] It is the perspective view showing the relation between the field on a steel bar, and an eddy current.
[Drawing 12] It is the development view in which developing perpendicularly and showing the hoop direction of the appearance of the detection unit 6.
[Drawing 13] It is the timing diagram which shows the example of a signal of the circuit of drawing 7 .
[Drawing 14] It is the block diagram showing the configuration of three-phase-circuit AC-power-supply 2A.
[Drawing 15] It is the mimetic diagram showing the configuration of the conventional example.
[Drawing 16] It is the mimetic diagram showing the configuration of the conventional example.
[Drawing 17] It is the mimetic diagram showing the configuration of the conventional example.
[Drawing 18] It is the mimetic diagram showing the configuration of the conventional example.
[Drawing 19] It is the mimetic diagram showing the configuration of the conventional example.
[Description of Notations]
1: Steel bar 1a: Crack
2A, 2B: Three-phase-circuit AC power supply 3: Signal generator
4: The 1st excitation unit 5: The 2nd excitation unit
6: Detection unit 6A, 6B: Detecting element
6Aa(s), 6Ab, 6Ac, 6Ad, ...: Coil plate
6Ba(s), 6Bb, 6Bc, 6Bd, ...: Coil plate
7: Detector 21: Three-phase-alternating-current power source
22: Thyristor bridge 23 28: Gate driver
24: Phase angle calculation machine 25: Inductor
26: Capacitor 27: Transistor bridge
29: Comparator 30: Chopping sea generator
40 50: Iron core
41-46, 51-56: Exiting coil guru-PU
47 57: Exiting coil 61: Resin substrate
62: Coil 63a, 63b: Lead wire
64: Lead wire

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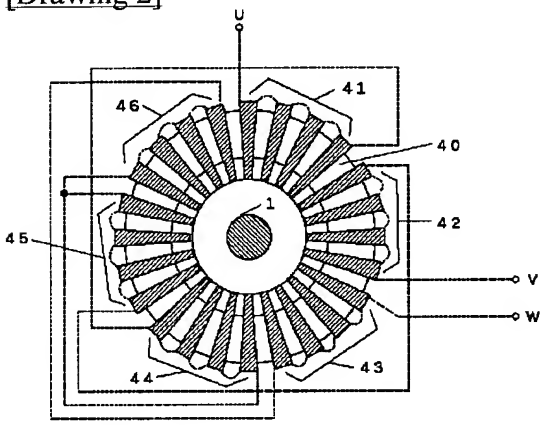
DRAWINGS

[Drawing 2]



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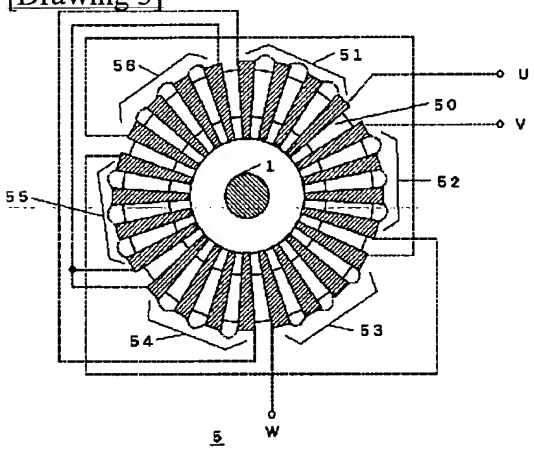
[Drawing 3]



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[Drawing 1]

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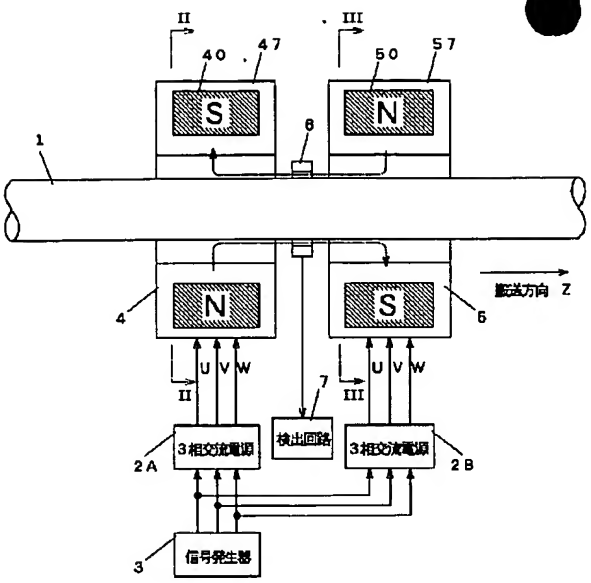

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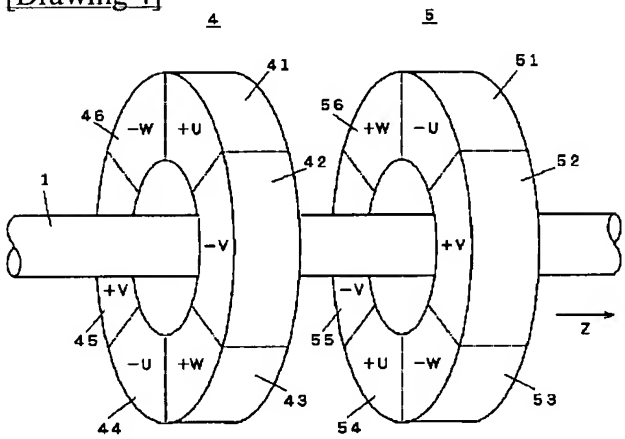

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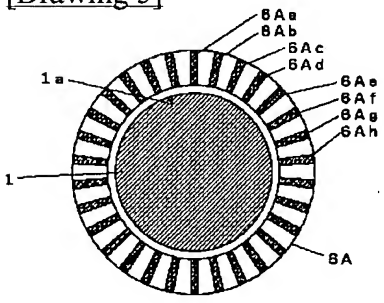

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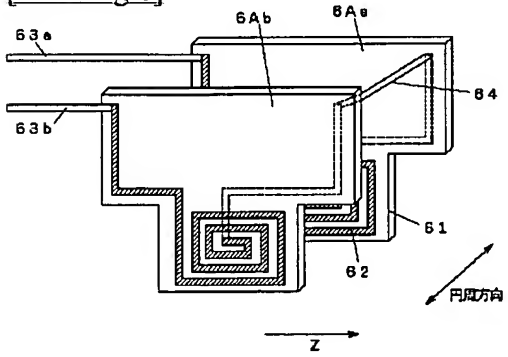

[Drawing 7]

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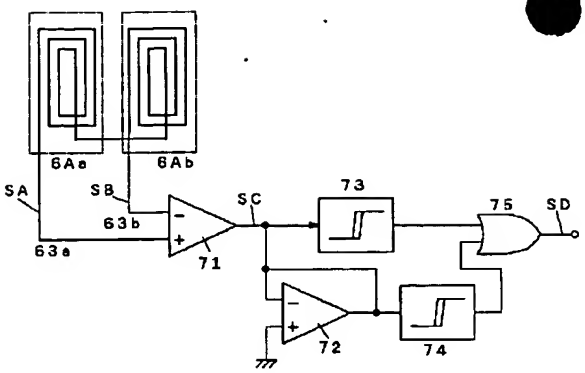

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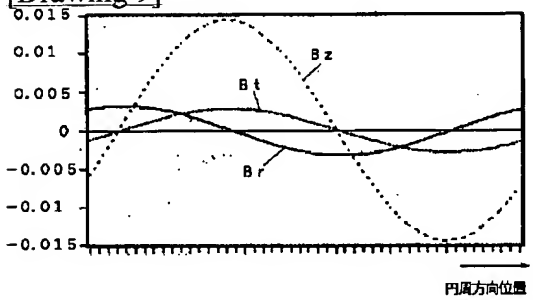
[Drawing 9]



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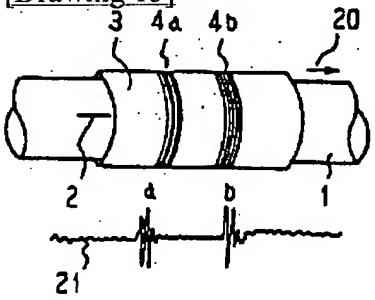

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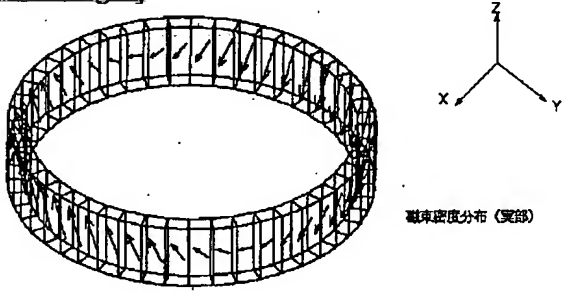

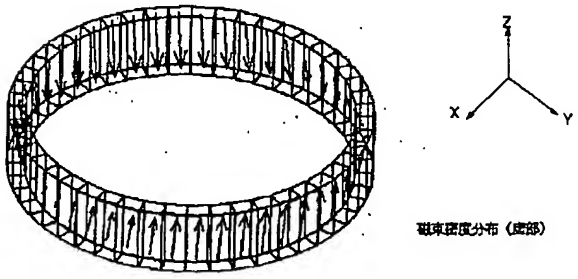

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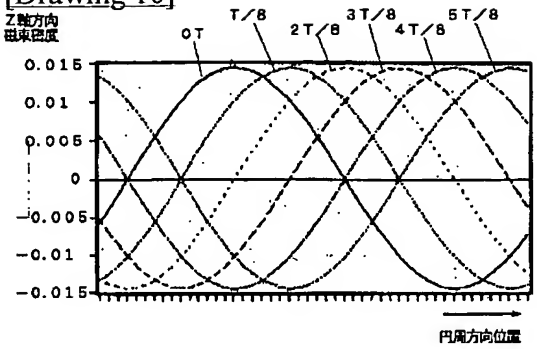
[Drawing 10]



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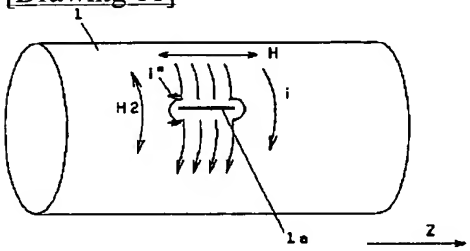

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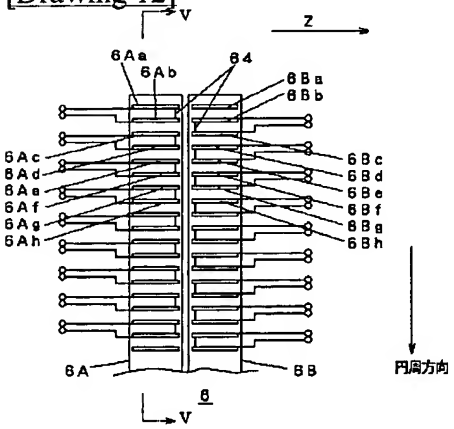
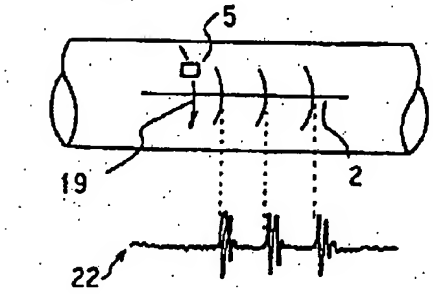


[Drawing 16]



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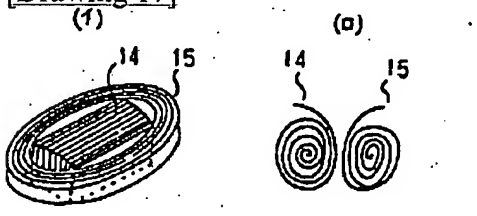

[Drawing 13]

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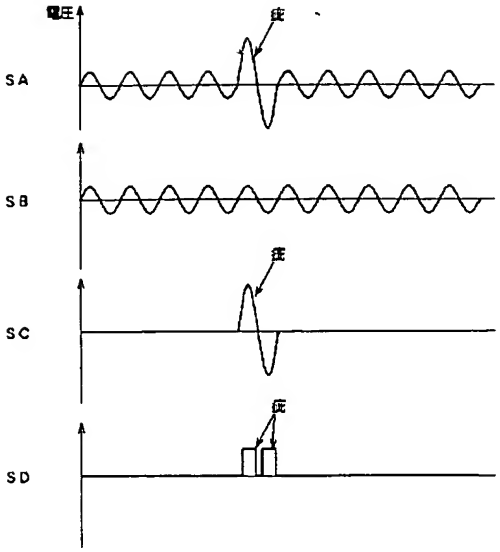
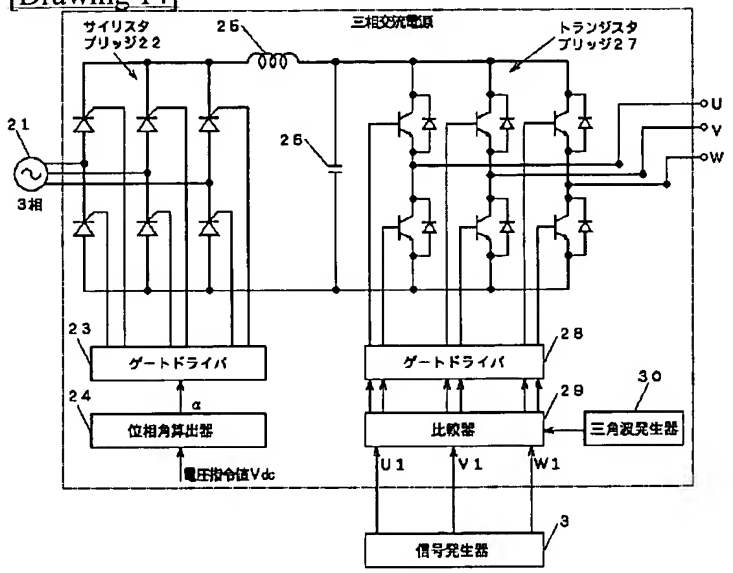


[Drawing 14]



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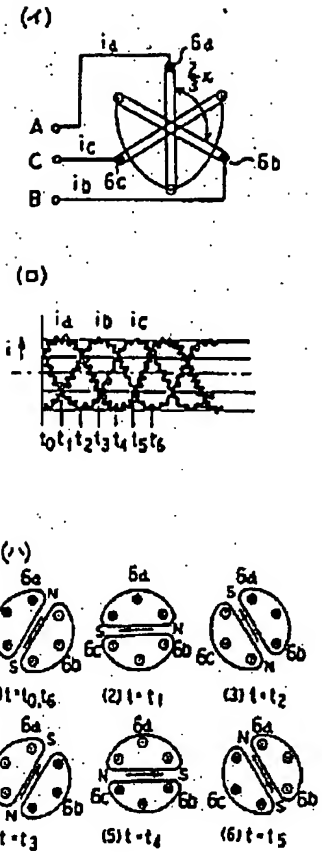

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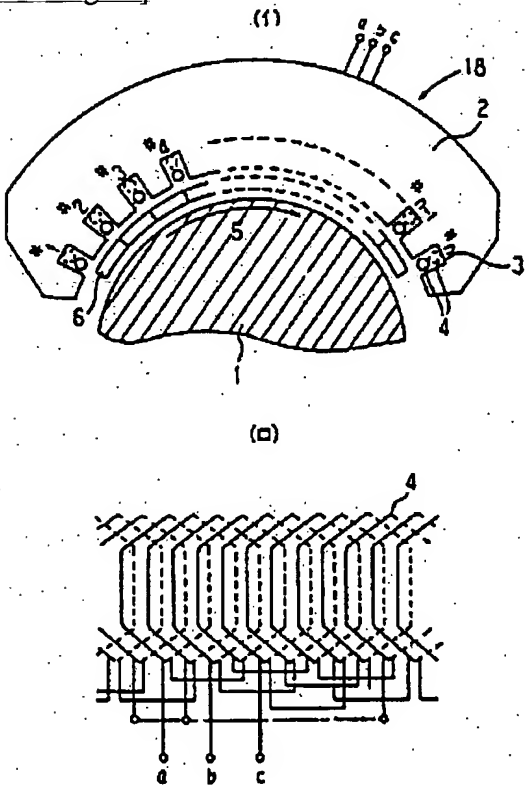

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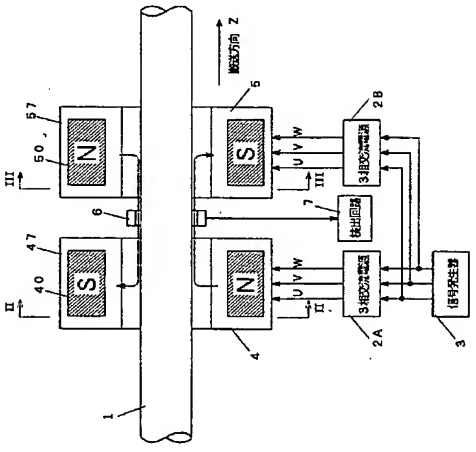
(54)【発明の名称】　導電体の疵検出装置

(57)【要約】

【目的】　疵検出信号のＳ／Ｎ比を改善し、搬送時の振動等によって検査対象物と検出部とのギャップが変動する場合でも、信頼性の高い検出結果を得る。

【構成】　環状の第１励磁ユニット４と第２励磁ユニット５とを検査対象物１の搬送方向に並べて配置する。第１励磁ユニット４と第２励磁ユニット５との搬送方向に互いに対向する位置に形成される磁極を異極にして、検出ユニット６の位置で搬送方向の磁界を生成する。三相交流電源を用いて磁界を円周方向に回転移動させる。検査対象物１に生じる渦電流の疵による変化を、検出ユニット６で磁界の変化として検出する。



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【特許請求の範囲】

【請求項１】　所定の軸方向に搬送される検査対象物の外周を囲む形である、第１の励磁手段；前記検査対象物の外周を囲む形であり、前記第１の励磁手段とは異なる位置に設置された、第２の励磁手段；前記第１の励磁手段と第２の励磁手段との間の、前記検査対象物の表面と対向する位置に設置された磁束検出手段；および前記第１の励磁手段と第２の励磁手段とが発生する磁界が、前記磁束検出手段の位置にて、前記検査対象物の搬送方向に向いていて、かつ、前記検査対象物の円周方向に回転するように、磁界を発生させる、励磁制御手段；を備える導電体の疵検出装置。

【請求項２】　所定の軸方向に搬送される検査対象物の外周を囲む形でほぼ環状に配列された複数の励磁コイルを含む、第１組の励磁手段；前記検査対象物の外周を囲む形でほぼ環状に配列された複数の励磁コイルを含み、前記軸方向に対して前記第１組の励磁手段とは異なる位置に設置された、第２組の励磁手段；前記第１組の励磁手段及び第２組の励磁手段が発生する磁界を、前記検査対象物の円周方向に回転するとともに、第１組の励磁手段と第２組の励磁手段の互いに前記軸方向に対向する励磁コイル対に、同一時点で互いに異なる磁極を形成する、励磁制御手段；および前記第１組の励磁手段と第２組の励磁手段との間の、前記検査対象物の表面と対向する位置に設置された磁束検出手段；を備える導電体の疵検出装置。

【請求項３】　前記磁束検出手段は、各々前記検査対象物の円周方向の一部分と対向する複数の検出手段を、前記検査対象物を囲む形で環状に配設してなり、更に前記複数の検出手段のうち互いに隣接する２つの検出手段が出力する信号の差分を検出する差分検知手段を含む、前記請求項２記載の導電体の疵検出装置。

【請求項４】　前記励磁制御手段は、３相以上の多相交流電源を含む、前記請求項２記載の導電体の疵検出装置。

【発明の詳細な説明】

【０００１】

【産業上の利用分野】本発明は、例えば棒鋼等の表面疵の検出に利用しうる導電体の疵検出装置に関する。

【０００２】

【従来の技術】例えば鉄鋼製品について表面疵を検出する場合、一般に渦流探傷方法や漏洩磁束探傷方法を用いて検査が実施される。渦流探傷方法においては、励磁コイルで発生した磁界の中に検査対象物を通し、検査対象物に渦電流を流す。そして、検査対象物の表面疵の有無に応じて渦電流が変化するので、その変化によって生じる磁束を検知コイル等によって検出する。漏洩磁束探傷方法においては、磁性体である検査対象物を磁化し、検査対象物の疵によってその外側に漏れる漏洩磁束をセンサを用いて検出する。

【０００３】渦流探傷法は、検出力が良い反面、被検材の表面状態の磁気的不均一に誘発される疑似不要雑音信号で妨げられる事が多く、このため一般にコイルを差動巻にして両コイルの信号の差によって表面疵の検査を行っている。

【０００４】図１５に、最も一般的に使用される自己励磁方式の貫通型コイルで被検材を検査する様子を示す。貫通型コイル３の励磁及び疵検知を行うコイル４ａ，４ｂは各々巻線方向が逆で差動巻となっており、被検材１にワレ疵２があり被検材１が貫通コイル３を矢印２０方向に通過する場合、２１に示す疵信号が得られる。貫通型コイル３によるワレ疵２の検知信号は、ワレ疵２が被検材１の長手方向にどんなに長くても同様であり、これはコイル４ａ，４ｂの信号の差を検知信号としているためワレ疵２のフロントでの信号ａとテイルでの信号ｂの２ケ所でしか信号が発生しない事による。また、検知信号は、ワレ疵２のフロント及びテイル部の疵形状によっても大きな影響を受け、疵が長手方向で急俊に変化すれば検知信号も高くなるが緩やかであれば検知信号が低く検出力が低下する等問題があり、貫通型コイル３によるワレ疵２の検出は、疵深さの大きい疵のみにとどまっていた。

【０００５】この様な貫通型コイルの欠点を解消するために、回転プローブ型が考えられている。これは、図１６に示す様に、励磁コイルと検知コイルを収納したプローブ５を矢印１９に示すように被検材１の断面周方向に回転させて、被検材１のワレ疵２に対して直角に通過させて、図１６に２２として示す様に、プローブ５がワレ疵横切る毎に疵信号を検知し、ワレ疵に対する検出力の向上を図るものである。しかし、プローブ５をワレ疵２に対して何回も横断させるためには、プローブ５を被検材１の回りで高速回転させねばならず、回転機構が複雑且つプローブ５の被検材１に対する追従が難しく、またワレ疵２が短い場合見逃す危険性も高い等問題も多い。

【０００６】この様な問題点を解消するための従来技術としては、例えば、特開昭６２－６１６２号公報，特開昭６２－６１６３号公報，特開昭６２－１２３３５２号公報，特開昭６２－１４５１６２号公報，特開昭６２－１７２２５８号公報，及び特開昭６２－１７２２５９号公報が公知である。

【０００７】特開昭６２－６１６２号公報では、励磁コイル及び検出コイルでなる検出ユニットを円周方向に多数設置し、励磁コイルにより検査対象物の円周方向又は断面方向の磁界を発生するとともに、多数の検出ユニットをスイッチで順次に切換えることによって円周方向の全体を検査可能にしている。

【０００８】また特開昭６２－６１６３号公報および特開昭６２－１２３３５２号公報では、励磁コイル及び検出コイルでなる検出ユニットを円周方向に多数設置し、励磁コイルにより検査対象物の円周方向又は断面方向の

磁界を発生するとともに、三相交流を用いて励磁コイルを励磁し、スイッチを用いることなく、励磁位置を円周方向に順次回転させるようにしている。

【０００９】また特開昭６２－１４５１６２号公報では、円周方向に多数設置された検出ユニットを互いに機械的に分離し、検出ユニット毎に検査対象物とのギャップを一定に維持するようにしている。

【００１０】特開昭６２－１７２２５８号公報および特開昭６２－１７２２５９号公報では、検査対象物の円周方向に順次に回転する磁界を発生するとともに、該円周方向に多数のセンサを配設し、発生した磁界の回転に同期して、多数のセンサの出力を順次にサンプリングする技術を開示している。

【００１１】

【発明が解決しようとする課題】これらの技術は、それぞれに利点はあるにしても、以下の共通の欠点を内在している。例えば、特開昭６２－６１６２号では、図１７に示すような励磁コイルと検出コイルを用いるため、また、特開昭６２－６１６３号及び特開昭６２－１２３５２号では図１８に示す励磁コイルを使用するため、更に特開昭６２－１４５１６２号では図１９に示す励磁コイルを使用するために、励磁コイルからの磁束は被検査材の半径方向に生ずる。これに対して、従来の図１５に示す貫通型の励磁方式では、被検査材の長手（軸）方向に磁束を発生させる。

【００１２】ところで、自動探傷におけるＳ／Ｎ（きず信号Ｓとベースノイズ Ｎとの比率であり、きずの検出しやすさを表す）は３倍以上必要と一般にいわれているが、この信号のＳ／Ｎは、検出器と検査対象物のギャップ変動により、検出器と検査対象物のギャップは小さい程、Ｓ／Ｎは良くなるが、実際の検査工程は、例えば、検査対象物である棒鋼を高速で搬送しながら検査を行うため、通材性との兼ね合いで極端にはギャップを狭くすることはできない。

【００１３】また、搬送によって検査対象物は振動するので、検出器と被検査材とのギャップは常時変動する。この際、励磁コイルからの磁束が被検査材の半径方向に生ずるとギャップ変動により磁束密度が著しく変化するため、ベースノイズの変動が大きいばかりか、きず信号の感度変化が極端に起こり、Ｓ／Ｎが著しく悪化する欠点がある。

【００１４】しかし、図１５に示すように、励磁コイルからの磁束を被検査材の軸方向に発生させた場合、ギャップ変動による、被検査材の半径方向の磁束密度の変化は比較的小さくなる利点がある。従って本発明は、前述のプローブ回転方式に代わって、被検査材の軸方向の磁束を周方向に回転させながら発生させる事で、検査対象物の疵に対して得られる信号のＳ／Ｎ比を改善し、疵検出の信頼性を高めることを課題とする。

【００１５】

【課題を解決するための手段】上記課題を解決するため、請求項１の導電体の疵検出装置は、所定の軸方向に搬送される検査対象物の外周を囲む形である、第１の励磁手段（４）；前記検査対象物の外周を囲む形であり、前記第１の励磁手段とは異なる位置に設置された、第２の励磁手段（５）；前記第１の励磁手段と第２の励磁手段との間の、前記検査対象物の表面と対向する位置に設置された磁束検出手段（６，７）；および前記第１の励磁手段と第２の励磁手段とが発生する磁界が、前記磁束検出手段の位置にて、前記検査対象物の搬送方向に向いていて、かつ、前記検査対象物の円周方向に回転するように、磁界を発生させる、励磁制御手段（２Ａ，２Ｂ）；を備える。

【００１６】また、請求項２の導電体の疵検出装置は、所定の軸方向に搬送される検査対象物（１）の外周を囲む形でほぼ環状に配列された複数の励磁コイルを含む、第１組の励磁手段（４）；前記検査対象物の外周を囲む形でほぼ環状に配列された複数の励磁コイルを含み、前記軸方向に対して前記第１組の励磁手段とは異なる位置に設置された、第２組の励磁手段（５）；前記第１組の励磁手段及び第２組の励磁手段が発生する磁界を、前記検査対象物の円周方向に回転するとともに、第１組の励磁手段と第２組の励磁手段の互いに前記軸方向に対向する励磁コイル対に、同一時点で互いに異なる磁極を形成する、励磁制御手段（２Ａ，２Ｂ）；および前記第１組の励磁手段と第２組の励磁手段との間の、前記検査対象物の表面と対向する位置に設置された磁束検出手段（６，７）；を備える。

【００１７】また、請求項３においては、前記磁束検出手段は、各々前記検査対象物の円周方向の一部分と対向する複数の検出手段を、前記検査対象物を囲む形で環状に配設してなり、更に前記複数の検出手段のうち互いに隣接する２つの検出手段が出力する信号の差分を検出する差分検知手段（７１）を含む。

【００１８】また、請求項４においては、前記励磁制御手段は、３相以上の多相交流電源を含む。

【００１９】なお上記括弧内に示した記号は、後述する実施例中の対応する要素の符号を参考までに示したものであるが、本発明の各構成要素は実施例中の具体的な要素のみに限定されるものではない。

【００２０】

【作用】請求項１の発明においては、第１の励磁手段（４）と第２の励磁手段（５）とがそれぞれ検査対象物（ｉ）の外周を囲む形で配置されており、第１の励磁手段（４）と第２の励磁手段（５）とは検査対象物が搬送される軸方向に対して互いにずれた位置に設置されている。また、前記第１の励磁手段と第２の励磁手段との間に、前記検査対象物の表面と対向するように、磁束検出手段（６，７）が設置されている。そして、励磁制御手段（２Ａ，２Ｂ）は、前記第１の励磁手段と第２の励磁

手段とが発生する磁界が、前記磁束検出手段の位置にて、前記検査対象物の搬送方向に向いていて、かつ、前記検査対象物の円周方向に回転するように磁界を制御する。

【００２１】また請求項２においては、第１組の励磁手段（４）と第２組の励磁手段（５）とがそれぞれ検査対象物（１）の外周を囲む形でほぼ環状に配列された複数の励磁コイルを含んでおり、第１組の励磁手段（４）と第２組の励磁手段（５）とは検査対象物が搬送される軸方向に対して互いにずれた位置に設置されている。そして、励磁制御手段（２Ａ，２Ｂ）は、第１組の励磁手段及び第２組の励磁手段が発生する磁界を、前記検査対象物の円周方向に回転するとともに、第１組の励磁手段と第２組の励磁手段の互いに前記軸方向に対向する励磁コイル対に、同一時点で互いに異なる磁極を形成する。また、磁束検出手段（６，７）は、第１組の励磁手段と第２組の励磁手段との間に、前記検査対象物の表面と対向するように設置される。

【００２２】このように構成すると、磁束検出手段が設置される第１組の励磁手段と第２組の励磁手段との間の空間における磁界は、前記軸方向の成分（Ｂｚ）が支配的になる。つまり、第１組の励磁手段の１つの磁極から第２組の励磁手段の１つの磁極へ（又はその反対に）向かう磁路が形成される。この磁路は、検査対象物の表面に隣接しているので、それを通る磁束によって、検査対象物上に渦電流が流れる。渦電流の流れる方向は各励磁手段によって生成された磁束の向きによって定まるが、検査対象物の表面に疵がある場合には、疵を迂回するように渦電流が流れる。磁束検出手段（６，７）は、検査対象物上の渦電流によって生じる磁束を検出する。従って、検査対象物上の疵の有無によって渦電流が変化すると、それが磁束検出手段で検出され、疵の有無が検出される。第１組の励磁手段及び第２組の励磁手段が発生する磁界は、検査対象物の円周方向に回転するので、円周方向の各々の位置の疵が検出可能である。

【００２３】本発明では、検査対象物をその搬送方向（Ｚ）に向かって平行に励磁させた状態で、疵の検出を実施するが、従来の疵検出装置では、検査対象物をその円周方向又は断面方向に励磁した状態で疵の検出を実施している。実験によれば、疵によって得られる信号のＳ／Ｎ比は、検査対象物が静止している状態、及び搬送によって検査対象物が振動している状態（磁束検出手段と検査対象物とのギャップが変動している状態）のいずれにおいても、本発明の装置の方が従来の装置よりもはるかに良い結果が得られた。従って、信頼性の高い疵検出が実現する。

【００２４】請求項３においては、磁束検出手段は、各々前記検査対象物の円周方向の一部分と対向する複数の検出手段を、前記検査対象物を囲む形で環状に配設してなり、更に前記複数の検出手段のうち互いに隣接する２つの検出手段が出力する信号の差分を検出する差分検知手段（７１）を含む。即ち、検査対象物の円周方向に互いに隣接する位置での磁束分布（渦電流によって生じる磁束分布）の変化が、検査対象物上の疵として検出される。

【００２５】請求項４においては、励磁制御手段は、３相以上の多相交流電源を含む。即ち、多相交流電源を用いて励磁磁界を回転させることによって、励磁磁界に生じる空間高調波を低減することができ、磁界のむらが小さくなり、より安定した疵検出が実現する。

【００２６】

【実施例】実施例の疵検出装置の構成を図１に示し、図１のII－II線断面を図２に示し、図１のIII－III線断面を図３に示す。まず図１を参照して説明する。検査対象物である棒鋼1は、熱間圧延ラインで製造されるものであり、その軸方向（長手方向）に高速で搬送されながら連続的に圧延される。この例では、仕上圧延工程の出側において、棒鋼１の通路を囲むように疵検出装置が配置されている。なお、疵検出装置の位置において、棒鋼１の温度はキューリ点以上であるため、棒鋼１は非磁性体である。

【００２７】疵検出装置の主要部は、３相交流電源２Ａ，２Ｂ，信号発生器３，第１励磁ユニット４，第２励磁ユニット５，検出ユニット６及び検出回路７で構成されている。第１励磁ユニット４は、棒鋼１を囲むように配置された環状の鉄心４０とそれに巻回された多数の励磁コイル４７で構成されている。励磁コイル４７は、実際には、図２に示すように円周方向に等間隔で配置された２４個のコイルでなっている。またこれらのコイルは点線で示すように結線されるので、これらは４個ずつ６組の励磁コイルグループ４１，４２，４３，４４，４５及び４６に区分される。即ち、図４に示すように、励磁コイルグループ４１，４２，４３，４４，４５及び４６は、それぞれ＋Ｕ相，－Ｖ相，＋Ｗ相，－Ｕ相，＋Ｖ相及び－Ｗ相の電源によって励磁される。

【００２８】同様に、第２励磁ユニット５は、棒鋼１を囲むように配置された環状の鉄心５０とそれに巻回された多数の励磁コイル５７で構成されている。励磁コイル５７は、実際には、図３に示すように円周方向に等間隔で配置された２４個のコイルでなっている。またこれらのコイルは点線で示すように結線されるので、これらは４個ずつ６組の励磁コイルグループ５１，５２，５３，５４，５５及び５６に区分される。即ち、図４に示すように、励磁コイルグループ５１，５２，５３，５４，５５及び５６は、それぞれ－Ｕ相，＋Ｖ相，－Ｗ相，＋Ｕ相，－Ｖ相及び＋Ｗ相の電源によって励磁される。

【００２９】図１に示すように、第１励磁ユニット４に供給する電力は、３相交流電源２Ａが生成し、第２励磁ユニット５に供給する電力は、３相交流電源２Ｂが生成する。３相交流電源２Ａ及び２Ｂは、信号発生器３が出

力する３相交流信号に同期して、それぞれ３相（Ｕ，Ｖ，Ｗ）の交流電力を生成する。従って、３相交流電源２Ａが出力する３相の交流電力と３相交流電源２Ｂが出力する３相の交流電力との位相は互いに同期する。

【００３０】そして、図４に示すように、棒鋼１の軸方向に対して、第１励磁ユニット４と第２励磁ユニット５の互いに対向する位置にある励磁コイルグループに供給される電力は互いに極性が逆になっている。つまり、例えば励磁コイルグループ４１の通電によって発生する磁極がＳ極の時には、励磁コイルグループ５１の通電によって発生する磁極はＮ極になる。また、励磁コイルグループ４１の通電によって発生する磁極がＮ極の時には、励磁コイルグループ５１の通電によって発生する磁極はＳ極になる。このため、第１励磁ユニット４と第２励磁ユニット５の互いに対向する方向、つまり棒鋼１の軸方向に向かう磁界が発生する。

【００３１】検出ユニット６は、棒鋼１を囲むように環状に構成されており、第１励磁ユニット４と第２励磁ユニット５の中間の位置に配置されている。第１励磁ユニット４と第２励磁ユニット５の励磁によって形成される、検出ユニット６の位置における棒鋼１の周囲の磁束密度分布を、コンピュータシミュレーションによって計算し求めた。その結果を図８に示す。なお、図８の上側に示した実部と下側に示した虚部とは、互いに電源波形の位相が９０度ずれた状態を示している。

【００３２】更に、検出ユニット６の位置における棒鋼１の周囲の磁束密度分布を各軸方向の成分に分解した結果を、円周方向各位置での磁束密度として図９に示す。図９において、Ｂｚ，Ｂｔ，及びＢｒが、それぞれＺ軸方向（棒鋼の長手方向），棒鋼の径方向，および円周方向の磁束密度を示している。つまり、検出ユニット６の位置における磁束密度については、Ｚ軸方向の成分が支配的であることが、図９から理解できる。

【００３３】また、検出ユニット６の位置におけるＺ軸方向の磁束密度分布の時間推移を図１０に示す。ここで、Ｔは信号発生器３が出力する信号の１周期（１／60秒）である。図１０を参照すると、磁束密度の分布が、時間とともに円周方向に移動することが理解できる。即ち、検出ユニット６の位置に形成される磁界は、棒鋼１の周囲を円周方向に回転する回転磁界になる。ある時点においては、図１に示すように、第１励磁ユニット４上に１つのＳ極と１つのＮ極とが形成され、第２励磁ユニット５上に１つのＮ極と１つのＳ極とが形成され、第１励磁ユニットのＳ極と第２励磁ユニットのＮ極との間、ならびに第１励磁ユニットのＮ極と第２励磁ユニットのＳ極との間の検出ユニット６の位置において、大きな磁束密度が得られる。

【００３４】次に、図１１を参照して説明する。上述のように、第１励磁ユニット４と第２励磁ユニット５を励磁すると、Ｚ軸方向の磁界Ｈが棒鋼１の表面近傍に生じる。この磁界Ｈによって、導電体である棒鋼１の表面には、円周方向に向かって渦電流ｉが流れる。但し、棒鋼１の表面に疵１ａが存在する場合、渦電流は疵１ａを迂回するように流れるので、疵１ａの近傍では、渦電流にＺ軸方向の成分ｉ″が生じる。この渦電流ｉ″によって、円周方向の磁界Ｈ２が生じる。疵１ａが存在しない時には、円周方向の磁界Ｈ２はほとんど生じない。従って、円周方向の磁界Ｈ２を監視すれば、疵１ａの有無を検出できる。

【００３５】検出ユニット６は、円周方向の磁界Ｈ２を検出するために設置されている。検出ユニット６の構成を図１２に示す。図１２は、検出ユニット６の外観を円周方向を縦方向に展開して示している。また、図１２のＶ－Ｖ線断面を図５に示す。図１２を参照すると、検出ユニット６はＺ軸方向に互いに近接した状態で並べた２列の検出部６Ａ，６Ｂで構成されている。検出部６Ａは、円周方向に等間隔で並べた３０個のコイル板６Ａａ，６Ａｂ，６Ａｃ，６Ａｄ，・・・・を備えている。検出部６Ｂも同様である。これらのコイル板は、円周方向に互いに隣接する２つずつが、それぞれ対になっている。

【００３６】１対のコイル板６Ａａ，６Ａｂの構成を図６に示す。コイル板６Ａａ及び６Ａｂは、各々、樹脂基板６１上にプリントされた箔状の導体によって形成される渦巻状のコイル６２を有している。コイル６２の外側の一端には、リード線６３ａ又は６３ｂが接続されている。コイル板６Ａａのコイル６２の内側の一端と、コイル板６Ａｂのコイル６２の内側の一端とは、導線６４によって互いに接続されている。他のコイル板６Ａｃ，６Ａｄ，６Ａｅ，６Ａｆ，・・・についても同様である。

【００３７】磁界Ｈ２によって生じる磁束が、コイル６２と鎖交し、コイル６２に電圧が誘起する。対のコイル板（例えば６Ａａ，６Ａｂ）と対向する位置の棒鋼表面に疵１ａが存在しない時には、２つのコイル６２に誘起する電圧はほぼ等しくなるが、対のコイル板の一方と対向する位置の棒鋼表面に疵１ａが存在し、他方の位置には疵が存在しない場合、２つのコイル６２に誘起する電圧に差が生じる。従って、疵１ａがある時には、リード線６３ａ，６３ｂ間に現われる電位差が大きくなるので、その電位差を監視することにより、疵１ａを検出できる。

【００３８】検出回路７のうち、一対のコイル板６Ａａ，６Ａｂに接続された部分の構成を図７に示す。また、図７に示す回路の各部の信号例を図１３に示す。図７を参照すると、差動増幅器７１は、コイル板６Ａａのコイルが誘起する電圧ＳＡと、コイル板６Ａｂのコイルが誘起する電圧ＳＢとの差分を増幅し、信号ＳＣとして出力する。信号ＳＣは、シュミットトリガ７３に入力されるとともに、反転増幅器７２を介してシュミットトリガ７４に入力される。信号ＳＣの振幅が所定以上になる

と、シュミットトリガ７３及び／又は７４の出力が高レベルHになる。オアゲート７５は、シュミットトリガ７３，７４が出力する信号に基づいて、疵検出信号ＳＤを生成する。他のコイル板（６Ａｃ，６Ａｄ，６Ａｅ，６Ａｆ，・・・）の対についても、それぞれ図７に示すものと同一構成の検出回路が接続されている。

【００３９】前述のように、第１励磁ユニット４と第２励磁ユニット５の励磁によって生じる磁界Hは、回転磁界であり、磁束密度の大きい部分が棒鋼１の円周方向に一定の速度で回転する。そして、棒鋼１上の磁束密度の大きい部分に渦電流が流れ、この渦電流を利用して疵の有無が検出される。従って、磁界Hの回転に伴なって、疵検出の対象になる位置も円周方向に移動する。棒鋼１上の疵１ａは、それと対向する位置に存在する対のコイル板（例えば６Ａａ，６Ａｂ）によって検出される。

【００４０】この実施例では、Ｚ軸方向に並べた２列の検出部６Ａ，６Ｂについて、コイル板の対が千鳥状になるように結線してある。即ち、図１２に示すように、１列目の検出部６Ａについては、コイル板６Ａａ・６Ａｂ，６Ａｃ・６Ａｄ，６Ａｅ・６Ａｆ，・・・がそれぞれ対をなしているが、２列目の検出部６Ｂについては、コイル板６Ｂｂ・６Ｂｃ，６Ｂｄ・６Ｂｅ，６Ｂｆ・６Ｂｇ，・・・がそれぞれ対をなしており、１列目の検出部６Ａの互いに隣接するコイル板対とコイル板対との間に、２列目の検出部６Ｂのコイル板対が位置している。

【００４１】例えば、円周方向のコイル板６Ａａ，６Ａｂの近傍の位置では、それらによって疵が検出されるが、コイル板６Ａｂ，６Ａｃの近傍では、コイル板対６Ａａ・６Ａｂ，又はコイル板対６Ａｃ・６Ａｄによって疵を検出することは難しい。しかし、コイル板６Ａｂ，６Ａｃの近傍では、２列目の検出部６Ｂのコイル板対６Ｂｂ・６Ｂｃによって疵を検出することができる。従って、円周方向のどの位置においても疵検出ができ、疵検出が不可能な領域（不感帯）は生じない。

【００４２】図１の三相交流電源２Ａの構成を図１４に示す。なお三相交流電源２Ｂの構成も図１４と同一である。図１４を参照して説明する。３相電源２１から供給される交流電力は、サイリスタブリッジ２２によって整流され、インダクタ２５及びコンデンサ２６によって平滑される。従って、コンデンサ２６の端子間には直流電圧が現われる。コンデンサ２６の端子間に現われる電圧は、サイリスタブリッジ２２がトリガされる位相に応じて変化する。位相角算出器２４に印加される電圧指令値Ｖdcは、コンデンサ２６の端子間に現われる直流電圧の調整に利用される。位相角算出器２４は、電圧指令値Ｖdcに対応するトリガ位相角αを算出する。ゲートドライバ２３は、位相角算出器２４が出力するトリガ位相角αでサイリスタブリッジ２２の各々のサイリスタをトリガするように、それぞれのゲート端子に印加するトリガ信号を生成する。即ち、各々のサイリスタがスイッチングする交流波形のゼロクロス点をそれぞれ検出し、ゼロクロス点を検出してから位相角αに相当する時間が経過した時に、トリガ信号を生成する。

【００４３】トランジスタブリッジ２７は、コンデンサ２６の端子間に現われる直流電圧をスイッチングし、三相交流電圧Ｕ，Ｖ，Ｗを生成する。トランジスタブリッジ２７のスイッチングを制御する信号は、比較器２９によって生成され、ゲートドライバ２８を介して各トランジスタのベース端子に印加される。比較器２９の入力端子には、信号発生器３の出力と三角波発生器３０の出力が接続されている。信号発生器３は、周波数が６０Ｈｚの正弦波の三相交流電圧Ｕ１，Ｖ１，Ｗ１を出力する。Ｕ１とＶ１およびＶ１とＷ１は、それぞれ１２０度の位相差を有している。また三角波発生器３０は、繰り返し周波数が３ＫＨｚの三角波信号を出力する。比較器２９は、６個のアナログ比較器を内蔵しており、三相交流電圧Ｕ１，Ｖ１，Ｗ１の正の半波及び負の半波の電圧を、それぞれ独立したアナログ比較器で三角波発生器３０が出力する三角波の電圧と比較し、それらの比較結果を６つの二値信号として出力する。これらの二値信号が、ゲートドライバ２８を介して、トランジスタブリッジ２７に印加され、トランジスタブリッジ２７の出力に三相交流電圧Ｕ，Ｖ，Ｗが現われる。

【００４４】この実施例の疵検出装置における疵検出信号（ＳＣ）は、非常に大きなＳ／Ｎ比を有していることが実験により確かめられた。また、検出ユニット６と棒鋼１とのギャップの変動量が１ｍｍ程度の場合であっても、深さが０．５ｍｍの疵に対して２．５程度のＳ／Ｎ比が得られることが分かった。

【００４５】なお上記実施例においては、検査対象物を棒鋼として説明したが、導電体であれば、他の材質のものでも検査可能である。また実施例においては、励磁ユニット４，５を付勢する電源として三相交流電源を用いたが、三相を越える多相交流電源を用いてもよい。相数が増えるに従って、励磁ユニット４，５によって生じる磁界の空間高調波がより低減されるので、より安定した疵検出が実現する。

【００４６】また上記実施例においては、検出ユニット６を円周方向に配設した多数のコイル板で構成したが、従来より公知の様々な構成の磁界検出器を用いても、疵を検出することが可能である。

【００４７】

【発明の効果】本発明では、検査対象物をその搬送方向（Ｚ）に向かって平行に励磁させた状態で疵の検出を実施するので、疵によって得られる信号のＳ／Ｎ比が従来と比べて大幅に改善され、信頼性の高い疵検出が実現する。また、励磁磁界を円周方向に回転するので、円周方向の各々の位置で疵検出ができ、長手方向の疵も円周方向の疵も共に検出可能である。

【００４８】また請求項３においては、検査対象物の円

周方向に互いに隣接する位置での磁束分布（渦電流によって生じる磁束分布）の変化を、検査対象物上の疵として検出するので、円周方向の小領域毎にそれぞれ疵の有無を検出することができ、検出性能が向上する。例えば、深さが大きく異なる複数の疵が互いに近接した位置に存在する検査対象物に対して両方の疵が検出可能である。

【００４９】また請求項４においては、多相交流電源を用いて励磁磁界を回転させることによって、励磁磁界に生じる空間高調波を低減することができ、磁界のむらが小さくなり、より安定した疵検出が実現する。

【図面の簡単な説明】

【図１】　実施例の疵検出装置の構成を示すブロック図である。

【図２】　図１のII－II線断面図である。

【図３】　図１のIII－III線断面図である。

【図４】　励磁ユニット４，５の励磁位相の分布を示す斜視図である。

【図５】　検出ユニット６を示す図１２のＶ－Ｖ線断面図である。

【図６】　一対のコイル板６Ａａ，６Ａｂを示す斜視図である。

【図７】　検出ユニット６と検出回路７の一部分を示すブロック図である。

【図８】　検出ユニット６の位置における磁束密度分布を示すベクトル図である。

【図９】　図８の磁束密度の各軸方向成分の円周方向分布を示すグラフである。

【図１０】　図９のＢｚの時間推移を示すグラフである。

【図１１】　棒鋼上の磁界と渦電流との関係を示す斜視図である。

【図１２】　検出ユニット６の外観の周方向を縦に展開して示す展開図である。

【図１３】　図７の回路の信号例を示すタイムチャートである。

【図１４】　３相交流電源２Ａの構成を示すブロック図である。

【図１５】　従来例の構成を示す模式図である。

【図１６】　従来例の構成を示す模式図である。

【図１７】　従来例の構成を示す模式図である。

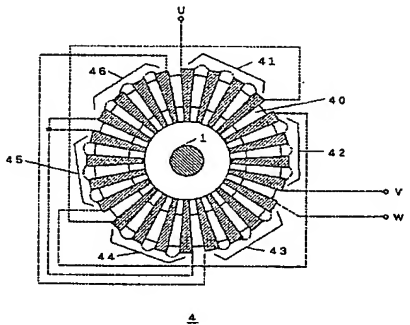
【図１８】　従来例の構成を示す模式図である。

【図１９】　従来例の構成を示す模式図である。

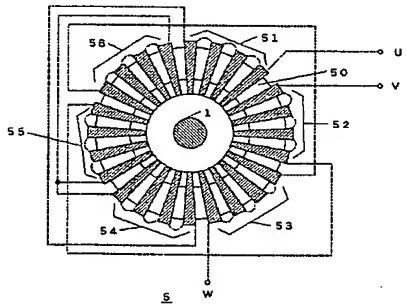
【符号の説明】

１：棒鋼	１ａ：疵
２Ａ，２Ｂ：３相交流電源	３：信号発生器
４：第１励磁ユニット	５：第２励磁ユニット
６：検出ユニット	６Ａ，６Ｂ：検出部
６Ａａ，６Ａｂ，６Ａｃ，６Ａｄ，	・・・：コイル板
６Ｂａ，６Ｂｂ，６Ｂｃ，６Ｂｄ，	・・・：コイル板
７：検出回路	２１：三相交流電源
２２：サイリスタブリッジ	２３，２８：ゲートドライバ
２４：位相角算出器	２５：インダクタブリッジ
２６：コンデンサ	２７：トランジスタ
２９：比較器	３０：三角波発生器
４０，５０：鉄心	
４１～４６，５１～５６：励磁コイルグループ	
４７，５７：励磁コイル	６１：樹脂基板
６２：コイル	６３ａ，６３ｂ：リード線
６４：導線	

【図２】



【図３】



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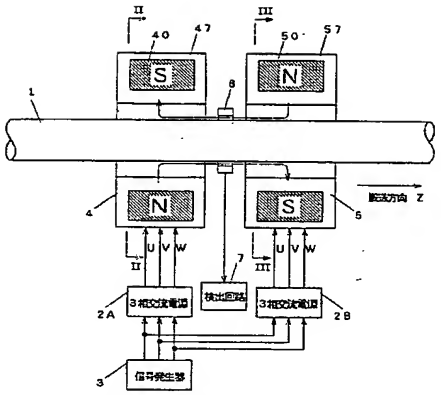
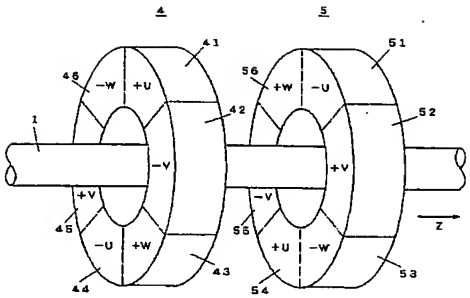
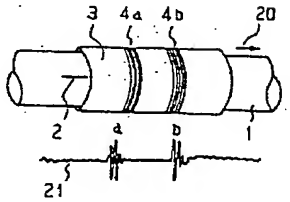
【図１】



【図４】



【図１５】



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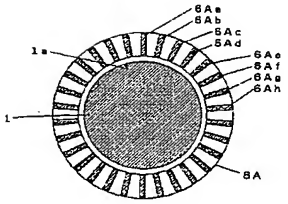

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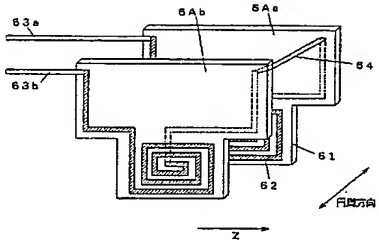

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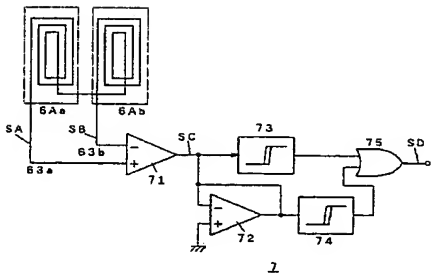

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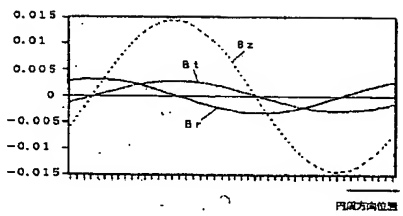

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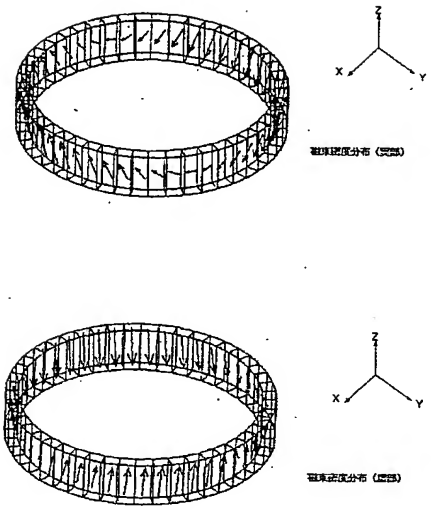

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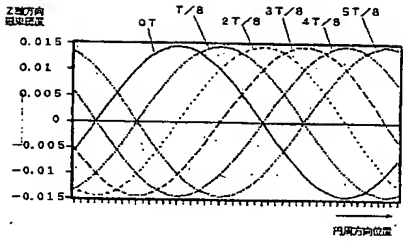

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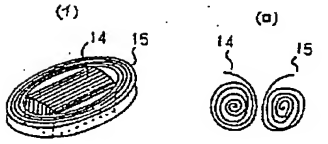

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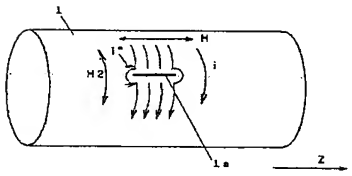

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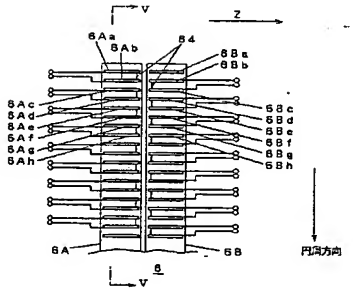

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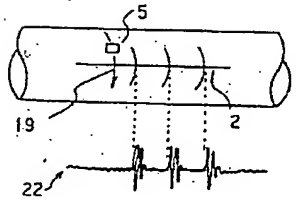

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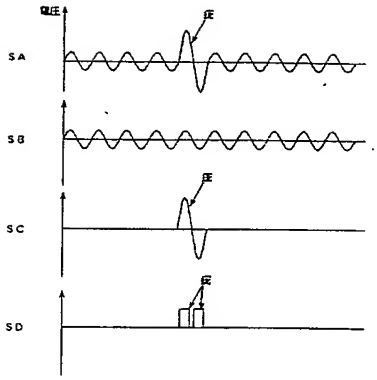

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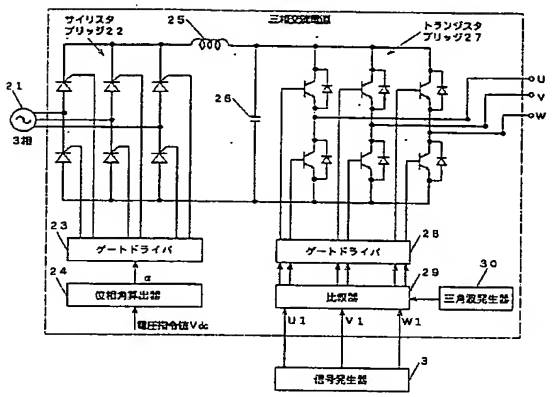

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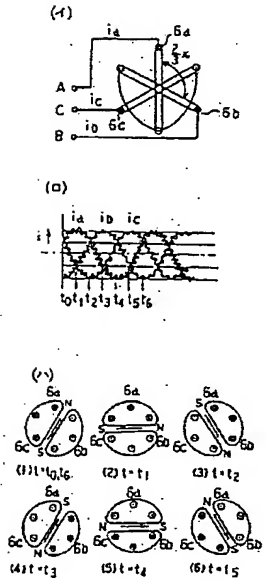

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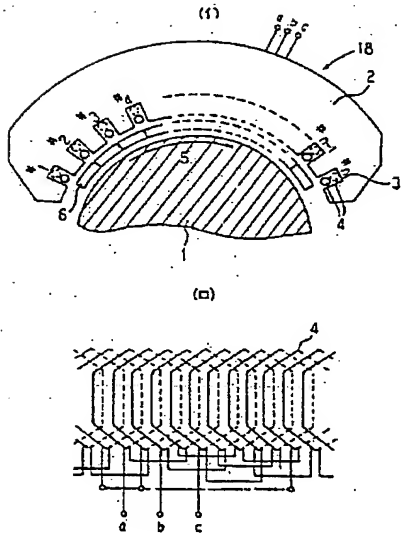

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